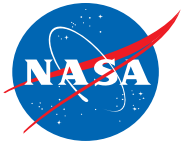



# Altitude Icing Testing of Jet Engines to begin at NASA Glenn Research Center Propulsion Systems Laboratory

**Tom Griffin**
**PSL Icing Project Engineer**
**John H. Glenn Research Center at Lewis Field**

PROPULSION SYSTEMS LABORATORY (PSL)

NASA – GLENN RESEARCH CENTER

CLEVELAND, OHIO

# JET ENGINE ICE CRYSTAL RESEARCH TESTING AT PSL


Tom Hoffman, Facility Manager

Dennis Dicki, Facility Engineer

Paul Lizanich, Senior Electrical Engineer

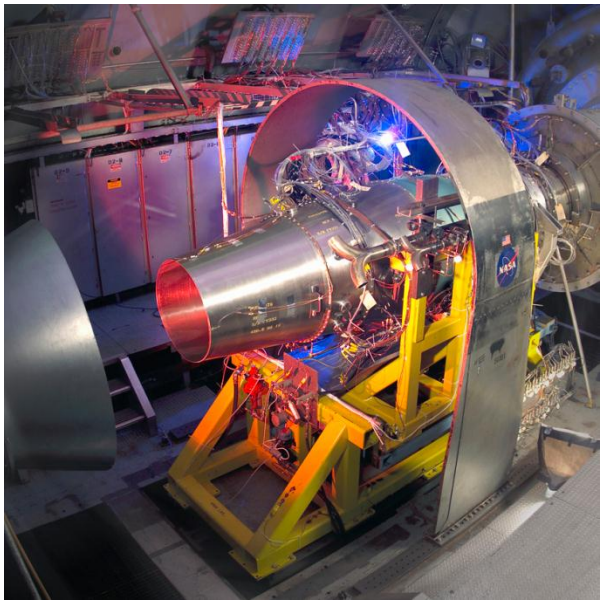
Mike Oliver, Icing Branch Research Engineer

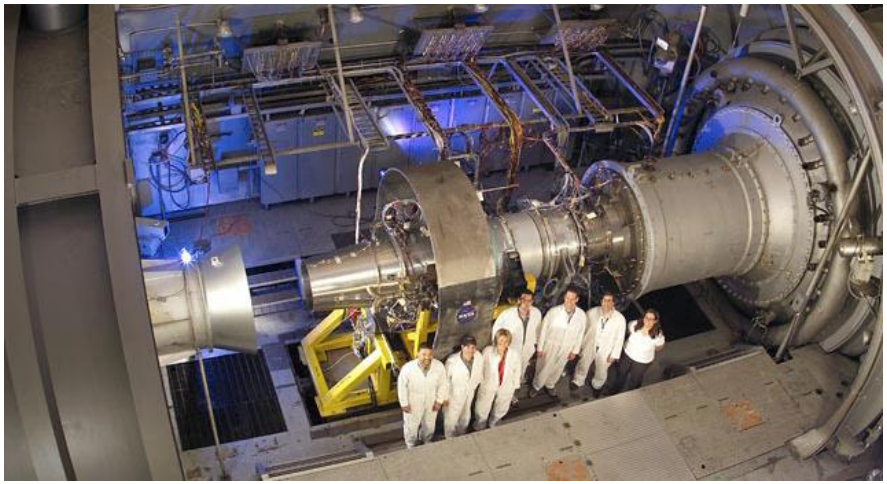
Dr. Judy VanZante, Cloud Specialist

Tom Griffin, Icing Project Engineer

# PSL Engine Testing

**National Research Facility**
**Commercial Development**
**National Defense Initiatives**
**Other Unique Applications**





- Engine Operability and Stall Resistance
- High Altitude Performance
- General Aviation and Business Jets
- Military Fighter Engine Development
- Helicopter Turbo-shaft Engines
- UAV/Missile Engines
- **Ice Crystal Research (new)**

# Propulsion Systems Laboratory

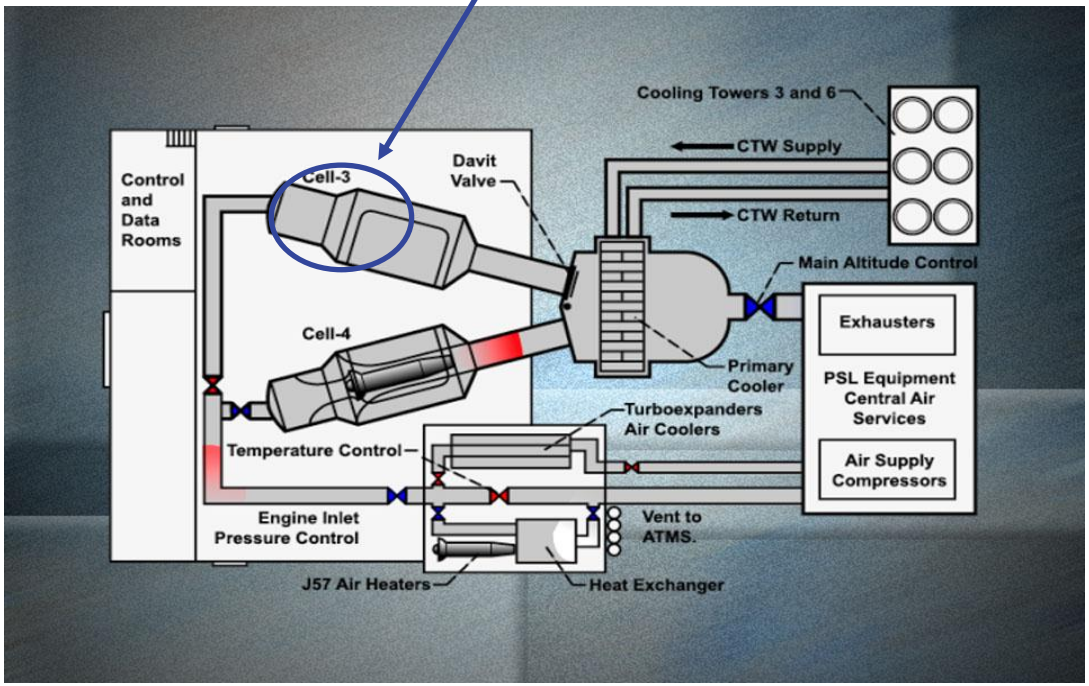
***NASA Glenn's Propulsion Systems Lab (PSL) is one of the Nation's Premier Direct Connect Altitude Simulation Facilities for Full-Scale Gas Turbine Engines and Propulsion System Research***

- **Two test sections share common inlet and exhaust**
- **Continuous Operation at high air flow rates**

  Altitude 90,000 ft (-90 deg F)

  PSL-3 Mach 3.0 (600 deg F)

  PSL-4 Mach 4.0 (1000 deg F)
- **Six component thrust system (50,000 lbf)**
- **Real time, high speed data acquisition and display**



# Progress/Plan
## PSL Icing System

- **Main Icing System Installation** (complete 6/2011)
  - Construction is 100% complete
  - Spray bars are installed in the inlet plenum
- **Test Cell Calibration/Engine Transition Hardware** (complete 3/2012)
  - Fabrication in progress
  - Includes instrumentation, camera systems, inlet ducting
- **Integrated Systems Test** (complete 4/2012)
  - System Checkouts
  - Full up Icing System Integrity and Check
- **Calibration Test** (complete 12/2012)
  - Verify Requirements are met and easily achievable
  - Document System Capabilities
- **Validation Test** (start 1/2013)
  - Seeking a cooperative test with engine manufacturer
  - Validate Against Existing Flight Data

# Objectives

## PSL Icing System

- Establishment of a ground-based, ice-crystal environment, engine test capability that includes altitude effects.
- Better understanding on how ice accretes inside an engine and how it affects engine performance and operability.
- Investigation and development of test methods and techniques that enable the effective and efficient study of engine icing due to ice-crystals along the path of airflow through the core of an engine.
- Development of validation data sets required to enable the creation of a system of computer codes that can be specifically applied to assess engine icing susceptibility as well as engine performance and operability effects.
- Collaboration with industry partners to utilize system to meet above objectives and facility utilization goals.

# Technical Challenges

## PSL Icing System

- Design and build an icing system that is versatile so it can be refined to meet developing engine icing requirements.
- Test methods for conducting pertinent engine core icing tests in PSL.
- The creation of methods and techniques needed to measure/monitor engine core ice accretions.
- A complete set of validation data sets including engine design geometry and operating conditions as well as atmospheric conditions for simulation of engine core icing events**.**
- A knowledgebase of engine core icing from which engineering tools to address the problem can be further developed.

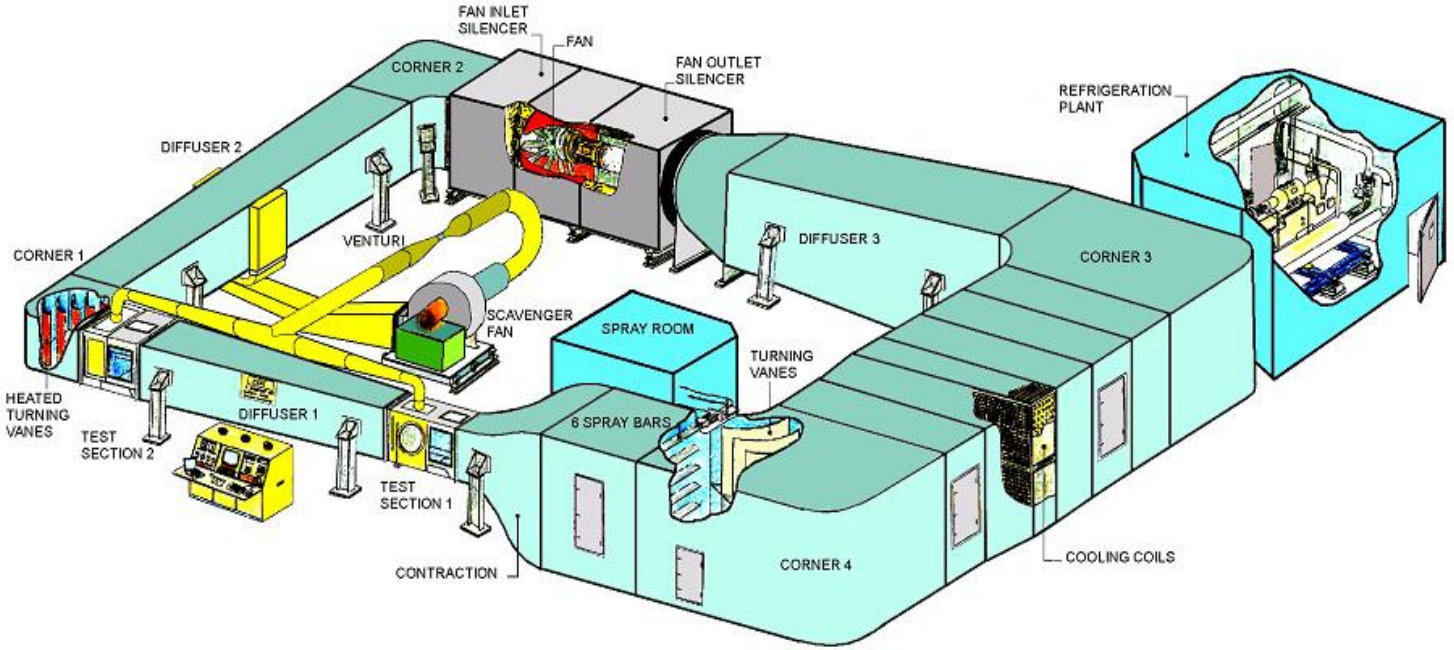
# Technical Approach
## PSL Icing System

- Icing system was designed and built to requirements established by collaboration with industry and government experts

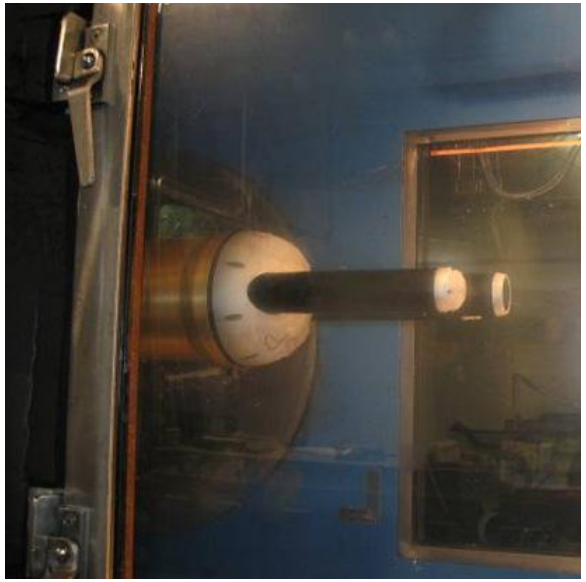
| Specified Requirement | | |
|---|---|---|
| **Specification** | **Minimum** | **Maximum** |
| Altitude (pressure) | 4000 ft | 40,000 ft |
| Inlet Total Temperature | -60°F | 15°F |
| Mach Number | 0.15 | 0.80 |
| Air Flow Rate | 10 lbm/sec | 330 lbm/sec |
| IWC (icing water content) | 0.5 g/$m^3$ | 9.0 g/$m^3$ |
| MVD (median volumetric diameter) | 40µ | 60µ |
| Run Time | Continuous up to 45 minutes | |

# Analysis
## PSL Icing System

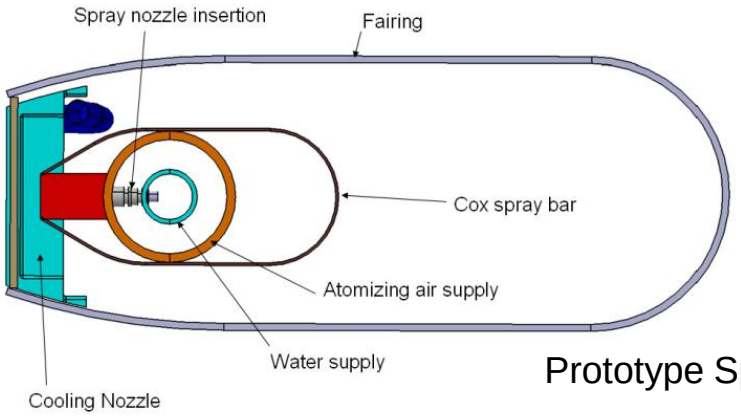
- Proof of concept tests, instrumentation evaluation and PSL simulation and computer simulation were performed by NASA and Cox & Co.
- Schematic of Cox and Co. Icing facility.



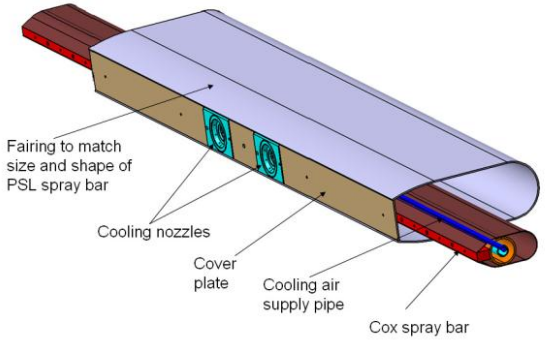
# Analysis
## PSL Icing System



- Parametrics include tunnel speed and temperature, nozzle type, cooling air pressure and temperature, spray bar atomizing air and water pressures and temperatures.
- FSSP and OAP used to determine median volume droplet size (MVD) and distribution
- Multi-wire probe used to determine liquid and total water content (LWC, TWC) and freeze fraction.

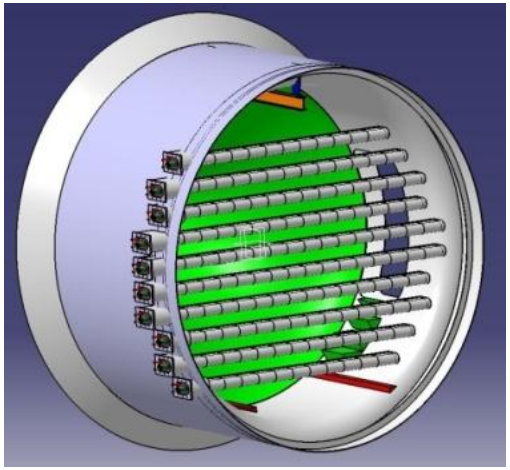



Prototype Spraybar

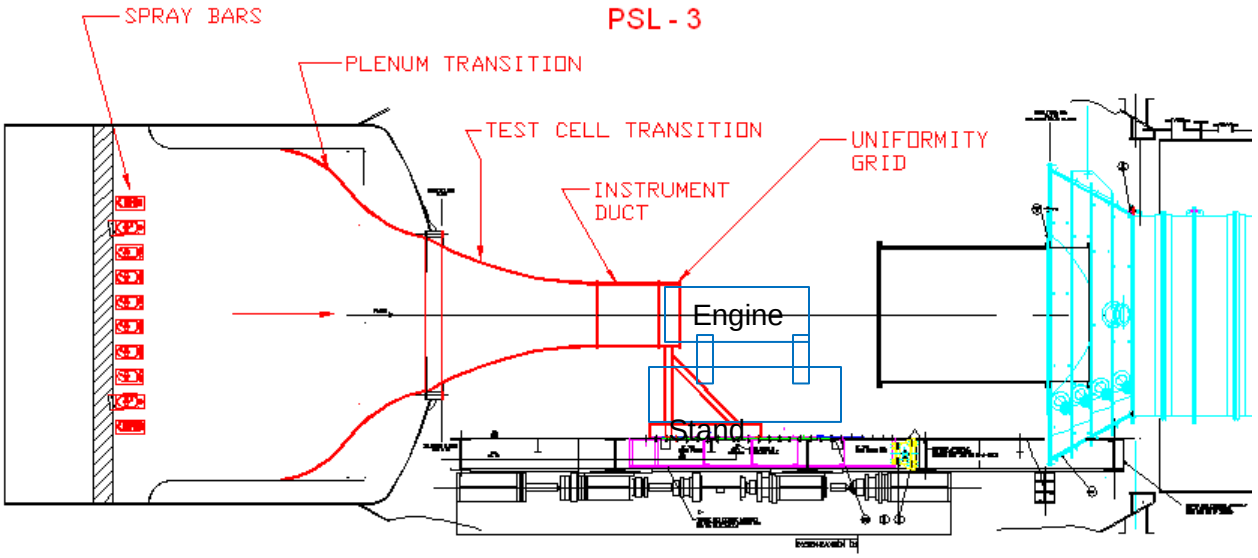


# System Description

## *Calibration Configuration*

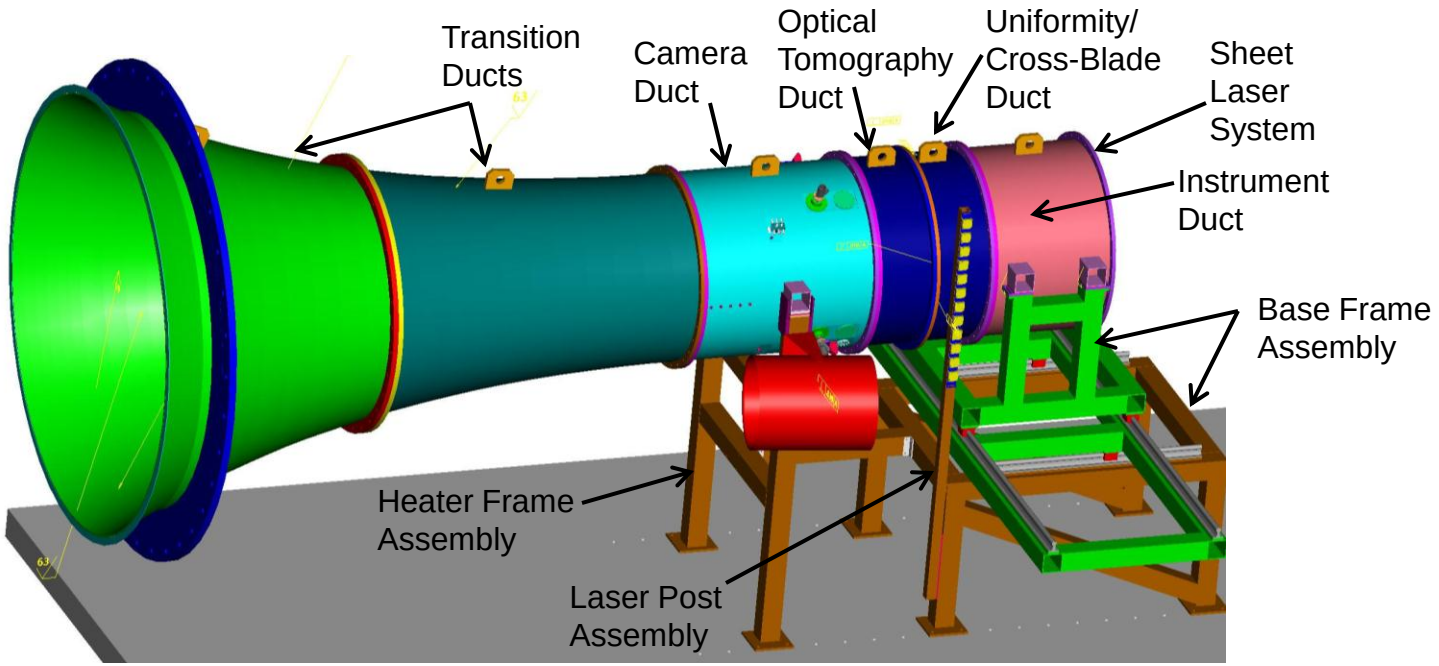


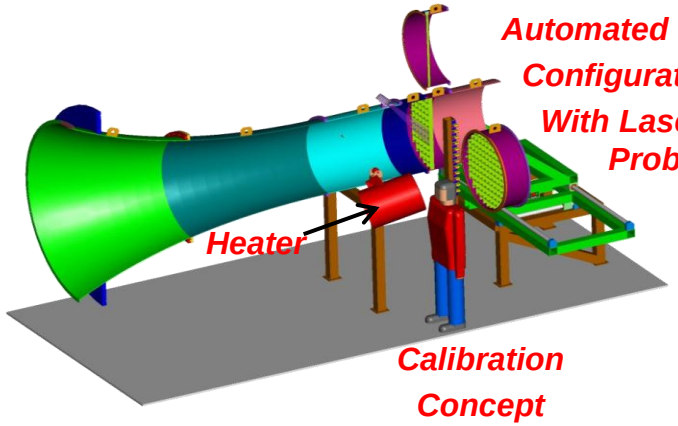
***Spray Bars***



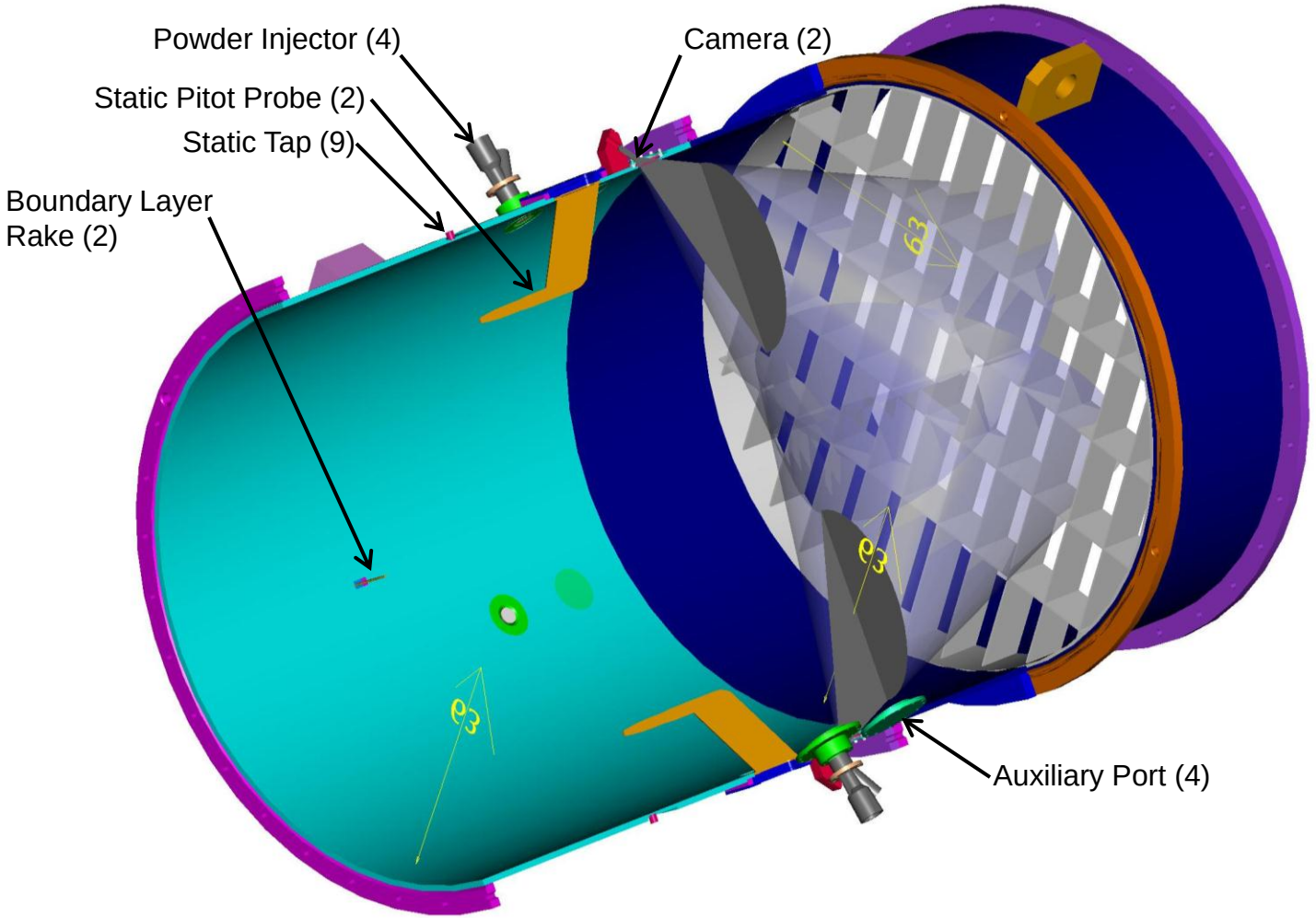

36” ID

# System Description
## Calibration Hardware

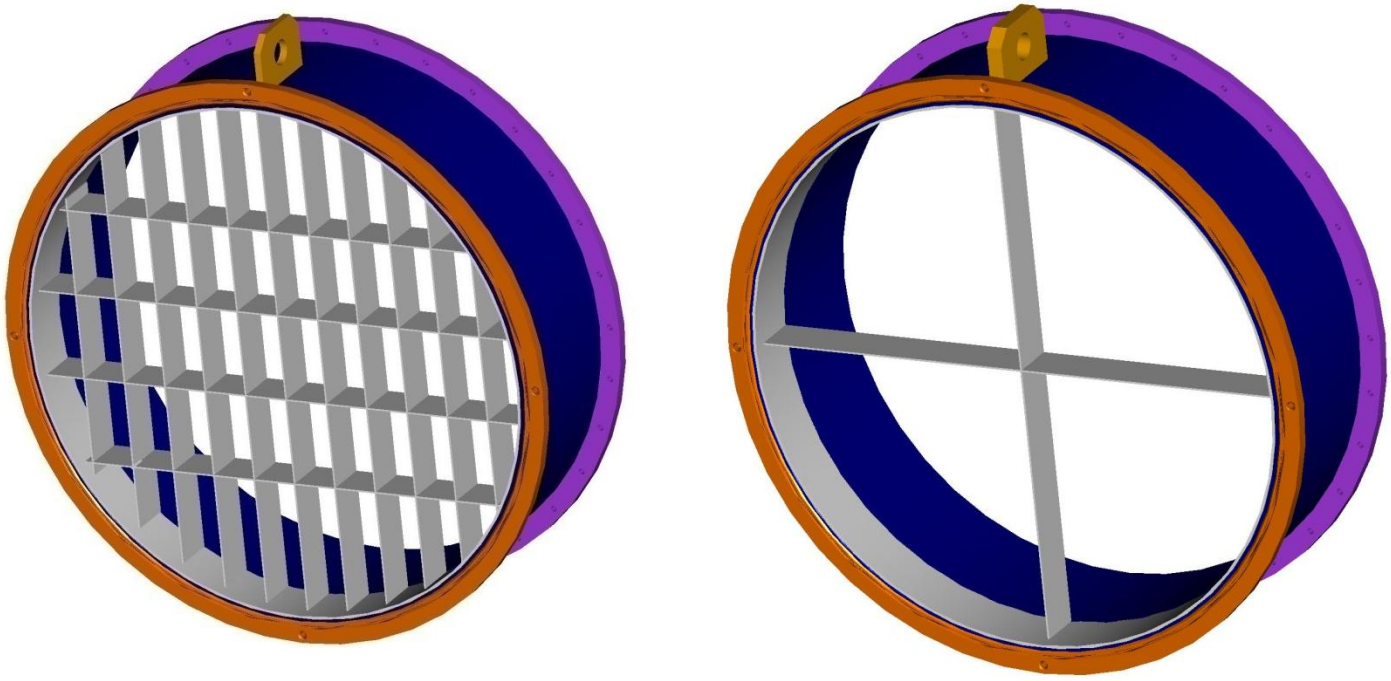


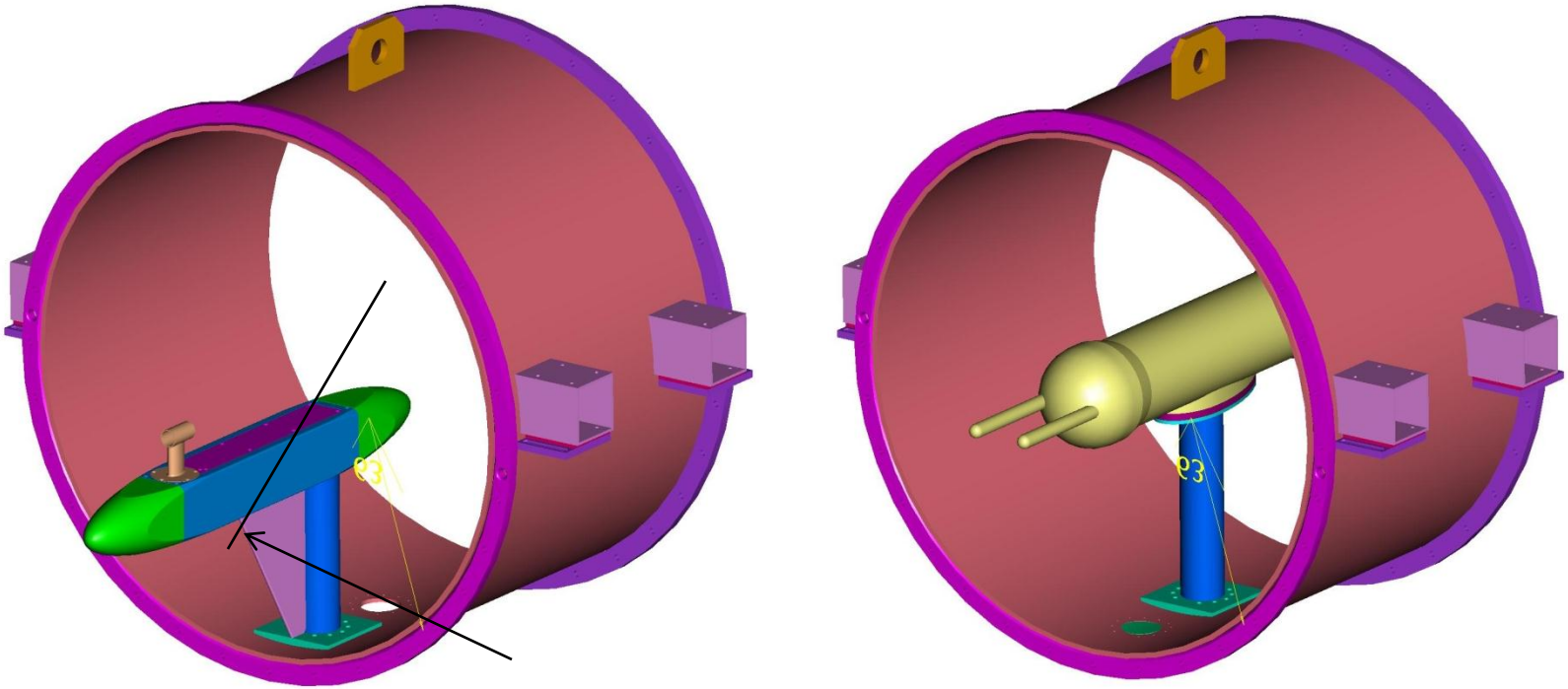
# Camera Duct Cutaway



# Uniformity/Cross Blade Duct



# Instrument Duct

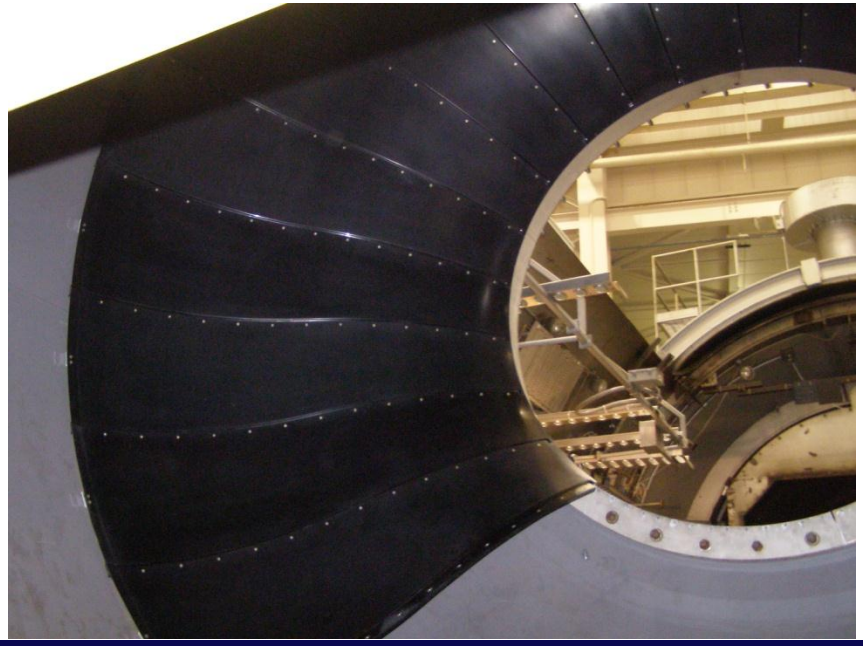


Shown with Multi-Wire (Left). CDP and CIP probes planned for particle sizing.

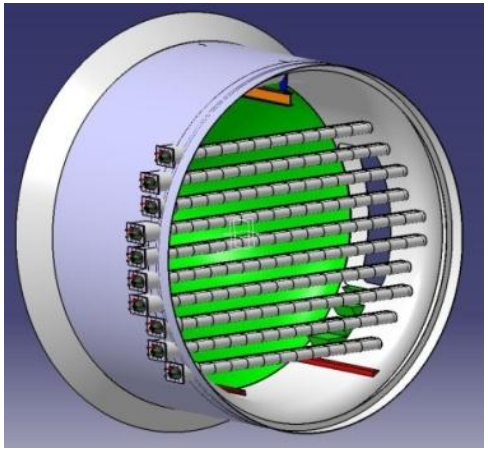
# System Description
## PSL Icing System

Spray Bars Installed in Plenum

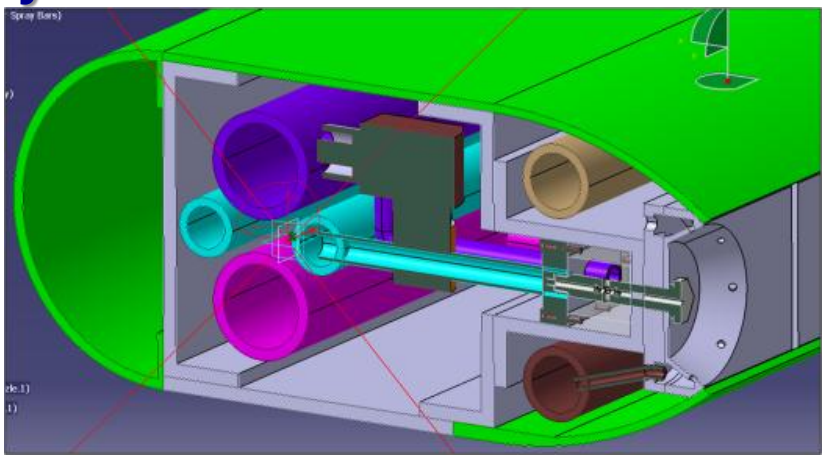
Transition Sections Installed in Plenum



# System Description
## PSL Icing System



PSL 3 Plenum Spray Bars

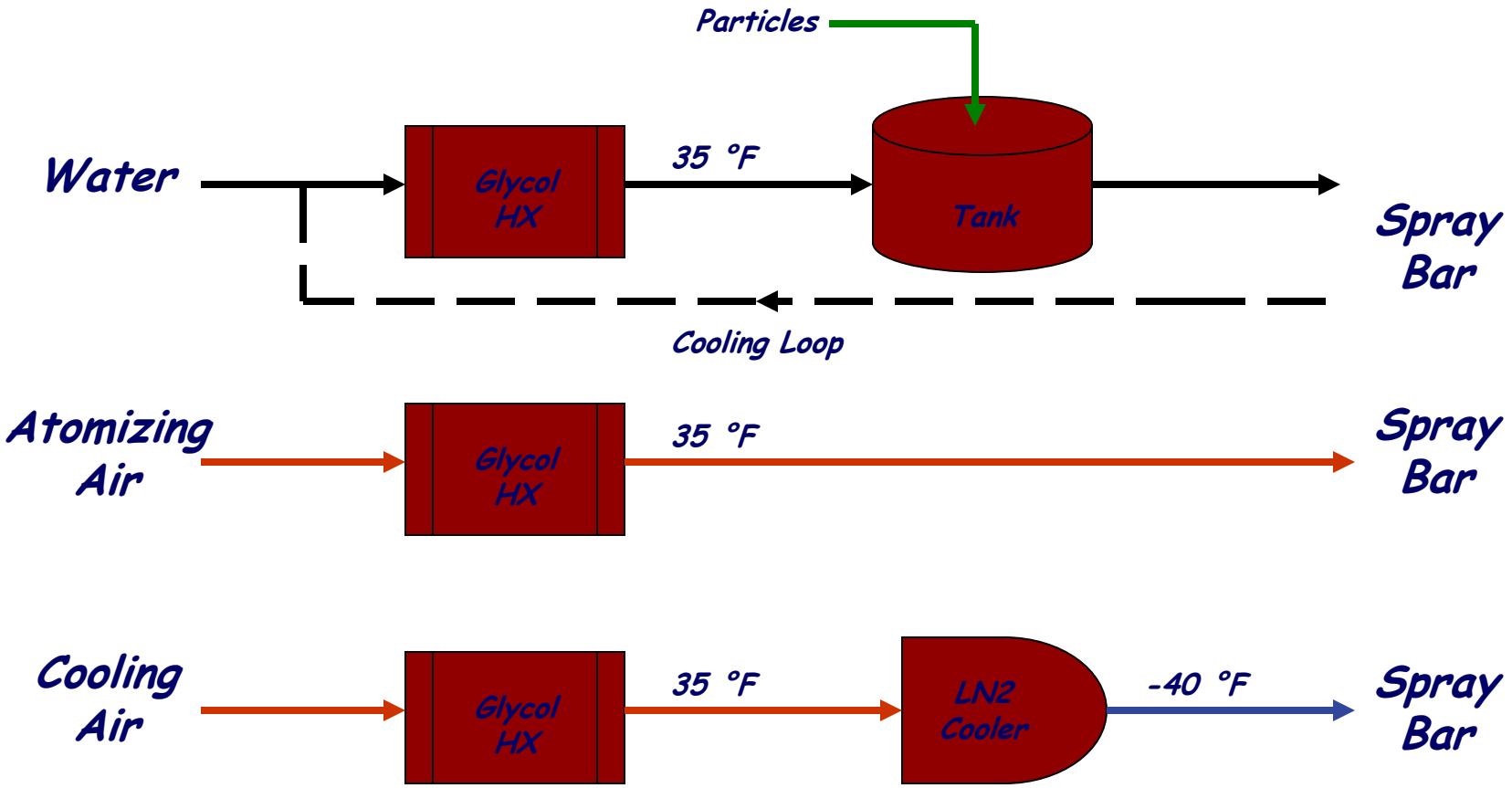


Spray Bar Detail

- 10 Spray Bars of 200+ Nozzles (2 types) mounted in PSL Cell 3 plenum that spray 35°F atomized water. Spray is cooled with -40°F air at nozzle exit to enhance freezing.
- System to be operated and controlled by the PSL Facility Control System from the Control Room.
- System emphasizes versatility, flexibility and portability. Spray bars are removable.

# System Description
## PSL Icing System

### *Subsystems Design Summary*



# System Description
## PSL Icing System

Water Tank

Air Dryer

Glycol Chiller

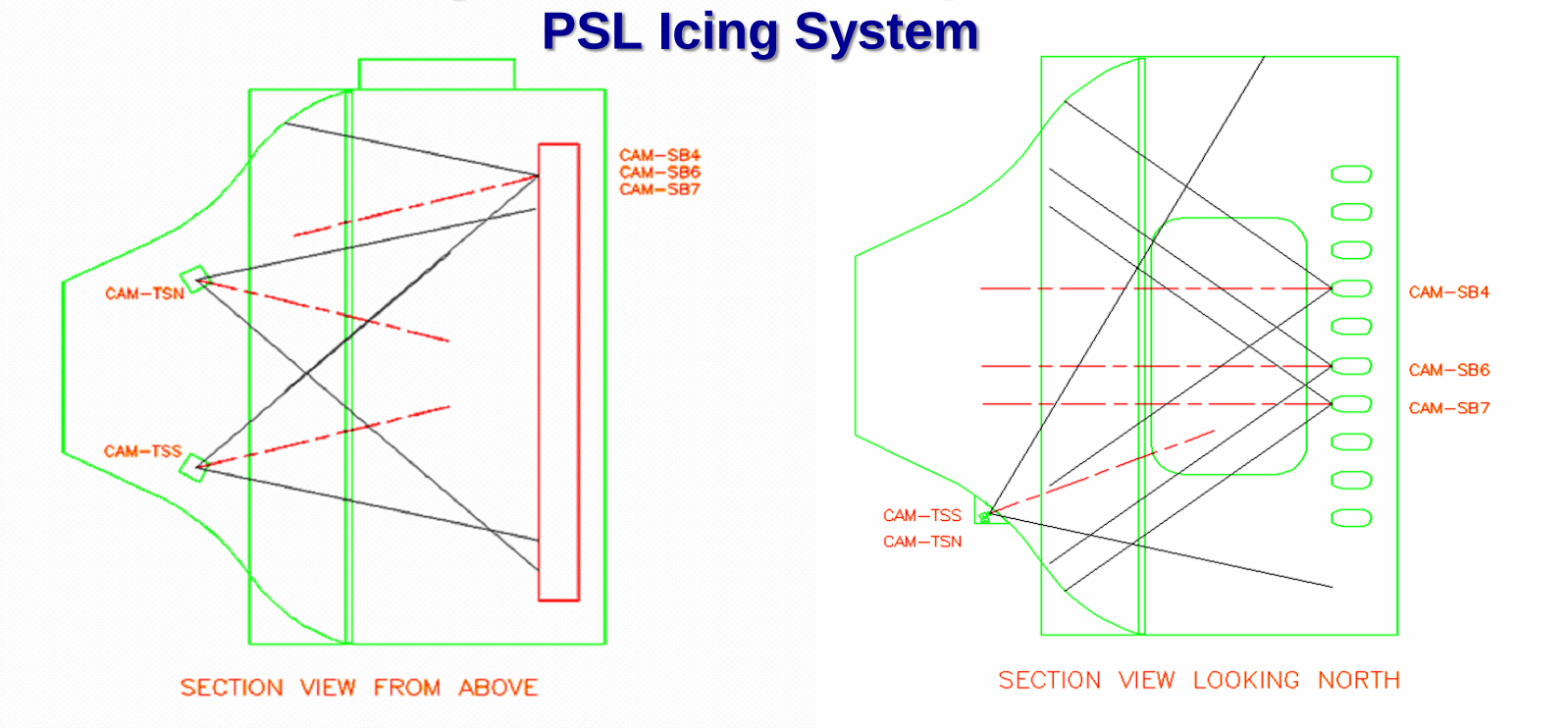
Outside Test Cell
Water Supply and Return Pipe
Atomizing and Cooling Air
Supply

Controls


Cooling/Atomizing Air HX

# System Description

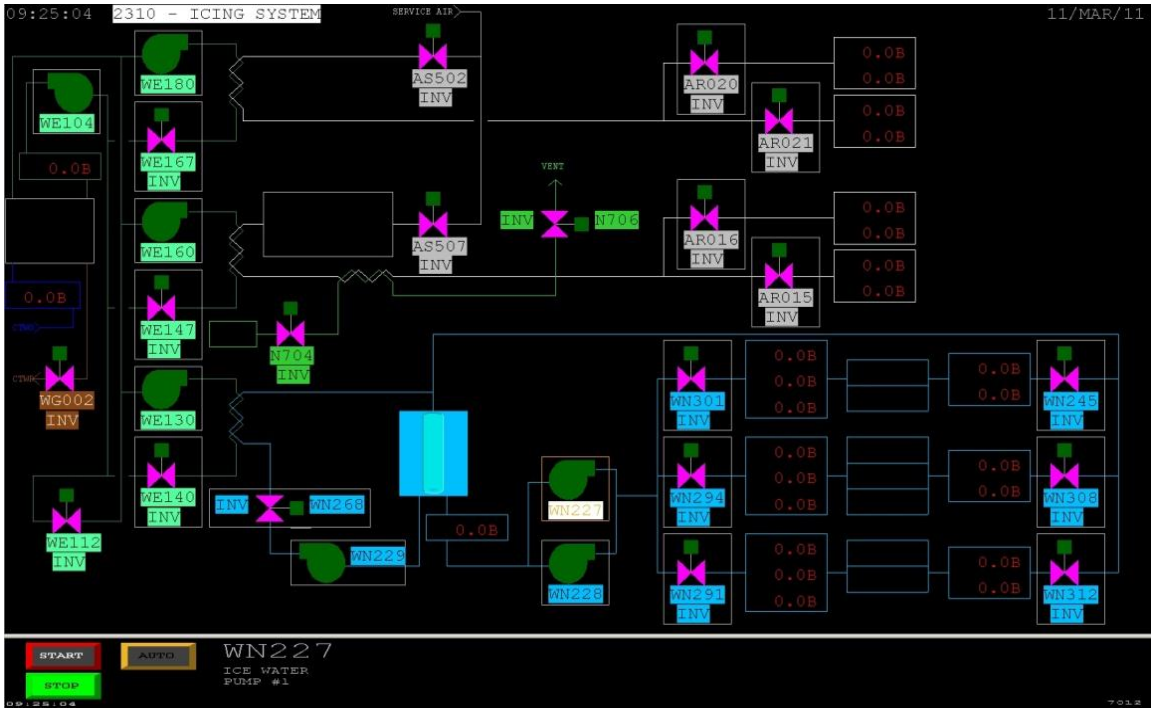
## PSL Icing System




- 5 cameras inside the plenum will provide a wide angle view of the spray bars, nozzles, plenum surfaces and ice cloud.
- To be displayed and recorded in control room for system integrity and ice cloud documentation.

# System Controls
## PSL Icing System

- Icing system control pages allow one operator to set desired conditions.




Icing System Control


Spray Bar Nozzle Pattern Control

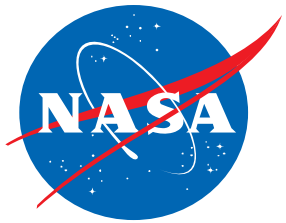

Spray Bar Control

# Questions?/Comments !

Contact Tom Hoffman, PSL Facility Manager
216-433-5637, thomas.r.hoffman@nasa.gov

# Backup Slides

Contact Tom Hoffman, PSL Facility Manager
216-433-5637, thomas.r.hoffman@nasa.gov


NASA